IMPACT OF POINTING ABERRATION IN GEOLOCATION OF MERCURY LASER ALTIMETER (MLA) TIME OF FLIGHT MEASUREMENTS. Haifeng Xiao [1], Serena Annibali [2], Alexander Stark [2], Hauke Hussmann [2] and Jürgen Oberst [1,2]. [1] Technical University Berlin, Institute of Geodesy and Geo-Information Science, D-12489 Berlin, Germany (haifeng.xiao@campus.tu-berlin.de); [2] German Aerospace Center (DLR), Institute of Planetary Research, D-10623 Berlin, Germany (alexander.stark@dlr.de).

Introduction: Laser altimeters (LAs) have been extensively used in a wide range of planetary research [1,2,3,4,5]. Besides the peculiarities of the measurement process of an altimeter, the data reduction can be also rather involving, in particular, when relativistic effects are taken into account. This paper discusses the geoprocessing step, which converts the time of flight (ToF) measurements, when supplied with trajectory and pointing information as well as appropriate planet rotation models, to geodetic coordinates of the footprints. We first propose four progressively refined geolocation models and then apply them to available laser altimeter data from space missions to investigate the effects of different approximations.

These data include Mars Global Surveyor (MGS) Mars Orbiter Laser Altimeter (MOLA) Precision Experiment Data Records (PEDR) (where instrument was nadir pointed from a circular orbit) and MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) Mercury Laser Altimeter (MLA) Reduced Data Records (RDR) MESSMLA2001 (with measurements characterized by large off-nadir pointing from an eccentric orbit).

We demonstrate that for a spacecraft on a highly eccentric orbit the effect of pointing aberration, caused by the relative velocity of the spacecraft with respect to the observer, can lead to significant lateral and radial shifts of the footprint position.

Proposed geolocation models: Four progressively refined models are proposed for the conversion of ToF measurements to geodetic coordinates: (1) Simultaneity Model (SM) which assumes the speed of light to be infinite and all events within the measurement process to be simultaneous [6]; (2) Spacecraft's Motion Model (SMM) that accounts for the spacecraft advancing along its orbit during ToF in a geometric solution; (3) Pointing Aberration Model (PAM) which takes a step further to take care of the pointing aberration induced by the relative velocity of the spacecraft with respect to the "observer" and (4) Special Relativity Model (SRM), which uses the Lorentz transformation to directly convert the variables in the reference frame centered at the spacecraft to that of the target body to account for effects of special relativity. Note that in the SMM and PAM models (2 and 3), solutions for different reference frames ("observers"), e.g., center of mass (CoM) of a planet or Solar-System Barycenter (SSB) may be supplied.

Table 1. Selected MOLA and MLA profiles.

Dataset	Flyby profiles	Orbital profiles
MOLA PEDR	None	1000;3000; 5000; 7000; 8000
MLA RDR MESSMLA2001	MLASCIRDR-0801141902; 0810060836	MLASCIRDR-1104010231; 1204011915; 1304010004; 1404011002; 1504012318

Selected MOLA and MLA profiles: For MOLA PEDR, five profiles in the mapping phase have been selected for the tests (Table 1). Due to the near-circular orbit configuration, the relative velocity of MGS with respect to the CoM of Mars is around 3.4 km/s. Thereby MOLA remained near nadir-pointed with off-nadir angles less than 1°.

For MLA RDR MESSMLA2001, apart from the two equatorial flyby profiles, five other profiles have been selected for tests (Table 1). The relative velocity of the spacecraft with respect to the CoM of Mercury is relatively high (6 to 7 km/s) for the flyby profiles compared to 3 to 4 km/s for the orbital profiles. Due to the fact that MESSENGER pointed its sunshade to the Sun, off-nadir angles generally increased southward and reached up to 50 to 60° for some profiles, but can also be almost zero for profiles acquired from a dawn-dusk orbit, in our case orbital profile MLASCIRDR-1304010004.

Applications to MOLA and MLA profiles: We begin with the ToF measurements for the profiles and compute geodetic coordinates of footprints from the four models. For MOLA, we first try to repeat the PEDR locations using the SMM model with Mars as the observer (supplied with the NAIF attitude kernels, orbit information from PEDR dataset) and the IAU2000 Mars rotational model [7]. Then, the model outputs of PAM and SMM both with Mars as the observer (both supplied with the attitude and refined orbit kernels from NAIF [8]) are compared to investigate the improvements that can be achieved by incorporating the pointing aberration.

For MLA, we first try to repeat the RDR MESSMLA2001 locations based on the SMM model with SSB as the observer (supplied with the same attitude and orbit kernels as RDR MESSMLA2001 has adopted) and the IAU2015 Mercury rotational model [9]. Then, the model outputs of PAM and SMM both with SSB as the observer (both supplied with the attitude and orbit kernels that adopted by RDR MESSMLA2001) are compared to investigate the improvements that can be achieved by incorporating the pointing aberration.

Also, in order to investigate the relation between SRM and PAM, the differences of SRM with respect to PAM with Mars as the observer (both supplied with the attitude and refined orbit kernels from NAIF [8]) are calculated for MOLA and the same is done with SRM and PAM with Mercury as the observer (both supplied with the attitude and orbit kernels that adopted by RDR MESSMLA2001) for MLA.

Results: The repetition experiments yield differences of less than 2 m laterally and within ±4 cm radially in the MOLA case and below 30 cm laterally and within -15 to 5 cm radially in the MLA case, thus both of these two datasets are demonstrated to have adopted the SMM model for the geolocation which ignores the pointing aberration effect, and while MOLA PEDR has selected Mars as the observer, MLA RDR MESSMLA2001 has selected SSB as the observer. Although adopting the PAM model instead of the SMM only makes insignificant improvements of 4 to 5 m laterally and up to ±3 cm radially for MOLA profiles, this figure enormously increases to be up to 150 m laterally and ±25 m radially for the MLA orbital profiles and up to 100 m laterally and -50 m radially for the flyby profiles (see Figure 1). The difference between SRM and PAM is within 0.1 mm laterally and 3 mm radially in the MOLA case and well within 2 cm laterally and 6 cm radially in the MLA case.

Conclusion: Although pointing aberration has been routinely applied in image, astronomy and radio science/radar data processing, the differences in the measurement scheme (i.e. active vs. passive) and the high measurement accuracy of the ToF in case of LA makes the geolocation of LA footprints not trivial, especially when the profiles are acquired from a highly elliptical orbit with significant off-nadir angles and large relative velocity with respect to the observer, like in the MLA case. The non-negligible impact of this pointing aberration (up to 100 m laterally and ±25 m radially for the MLA orbital profiles) on Mercury parameters and MESSENGER data products needs to be studied in further research.

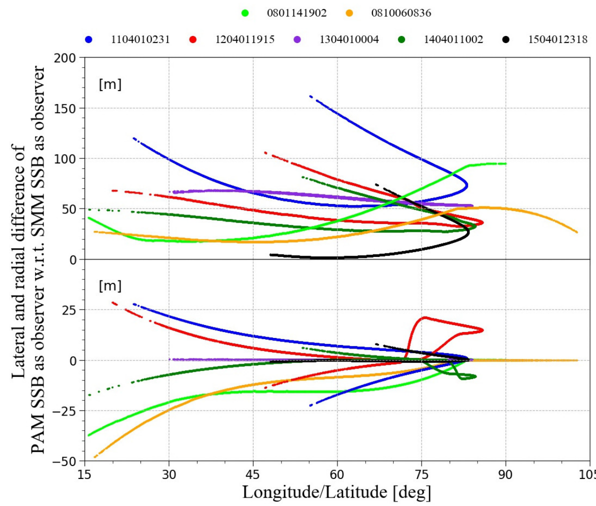

Figure 1. Lateral (upper) and radial (lower) difference of PAM with SSB as observer with respect to SMM with SSB as observer plotted against latitude (MLA orbital profiles) and longitude (MLA flyby profiles in light green and orange).

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